



---

# **Recent results on nanoscale magnetic systems from soft x-ray resonant magnetic reflectivity at SLS**

J.-M. Tonnerre,  
Laboratoire de Cristallographie  
CNRS-Grenoble

"Magnetic Nanostructures, Interfaces, and New materials: Theory,  
Experiment, and Applications", ALS October 19-20, 2004

# OUTLINE

---

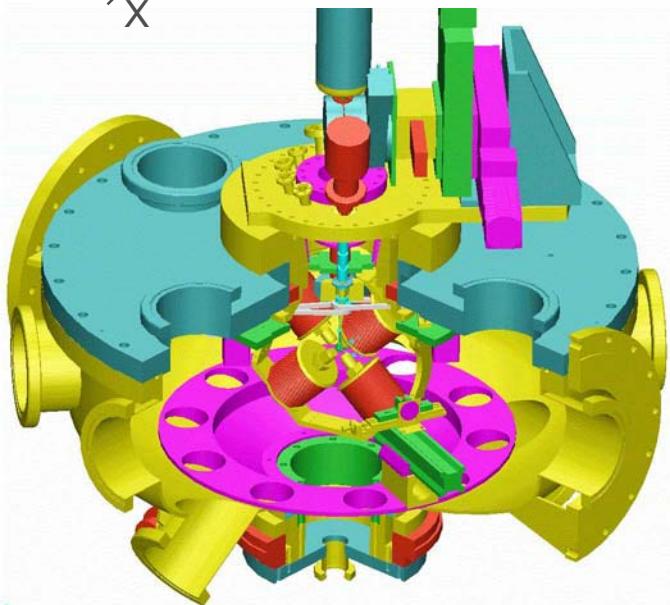
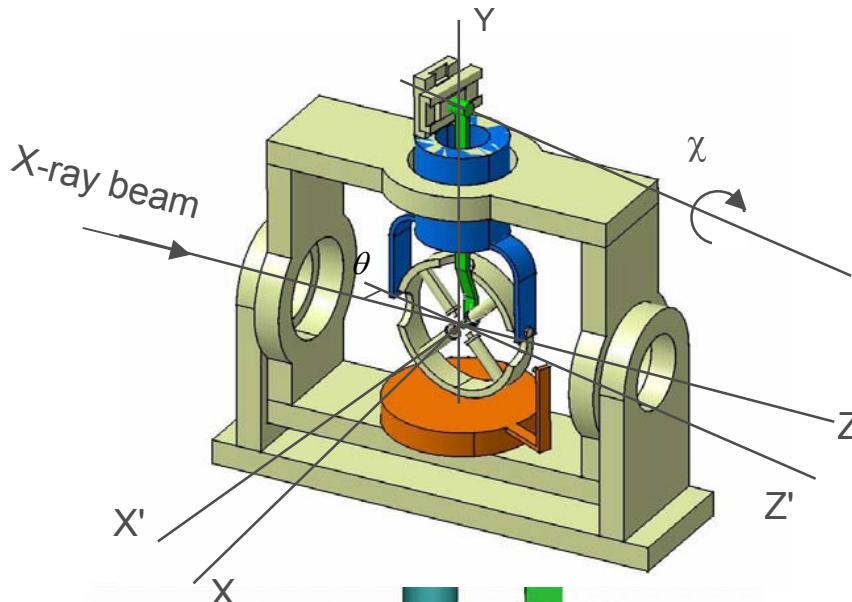
- Introduction
- The experimental set-up
- Performance
  - investigation of an exchange coupled trilayer
- Analysis of soft x-ray resonant reflectivity
- FePt/C a granular magnetic multilayer
- Summary

# Introduction

---

- Use of the magnetic dichroic contrast in a reflectivity measurement
- Analysis of intensity changes for 2 opposite directions of an applied magnetic field and or 2 polarisation states
- Change in the dielectric tensor and refraction index
- $f'(E)$ ,  $f''(E)$ ,  $m'(E)$ ,  $m''(E)$  strongly resonant at  $L_{2,3}$  edges of  $M_{4,5}$  of 3d element and rare-earths
- wave lengths well-suited for nanoscale systems
- measurements need chamber under vacuum and scattering capabilities

# The UHV reflectometer



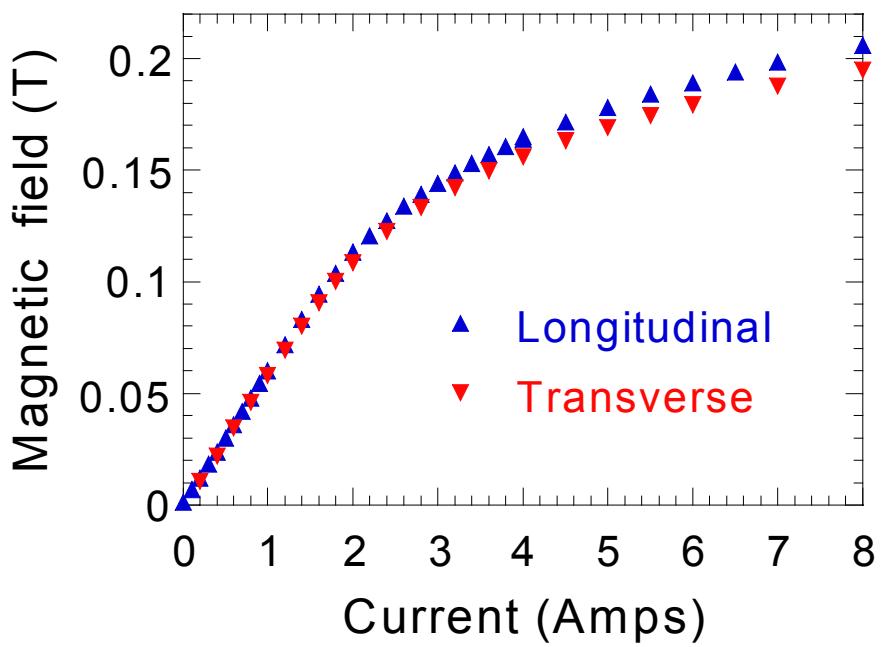
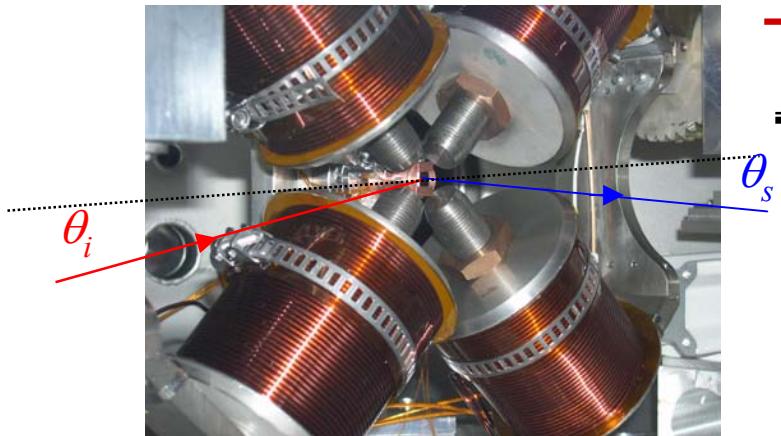
- Large volume  $\theta/2\theta$  goniometer
- Sample manipulator (xyz+ tilt  $\chi$ )
- Four coils device at 45 °(H = 0.2T at max)
  - easy change transverse to longitudinal configuration
  - foldaway system
- Sample transfer (along X)
- $3 \times 10^{-9}$  mbar w.o. field
- $10^{-8}$  mbar range w. field
- Continuous-flow helium cryostat system
- Photodiode detector
- Out-plane field → transmission geometry

Urs Staub( SLS) collaboration, **RESOXS** project

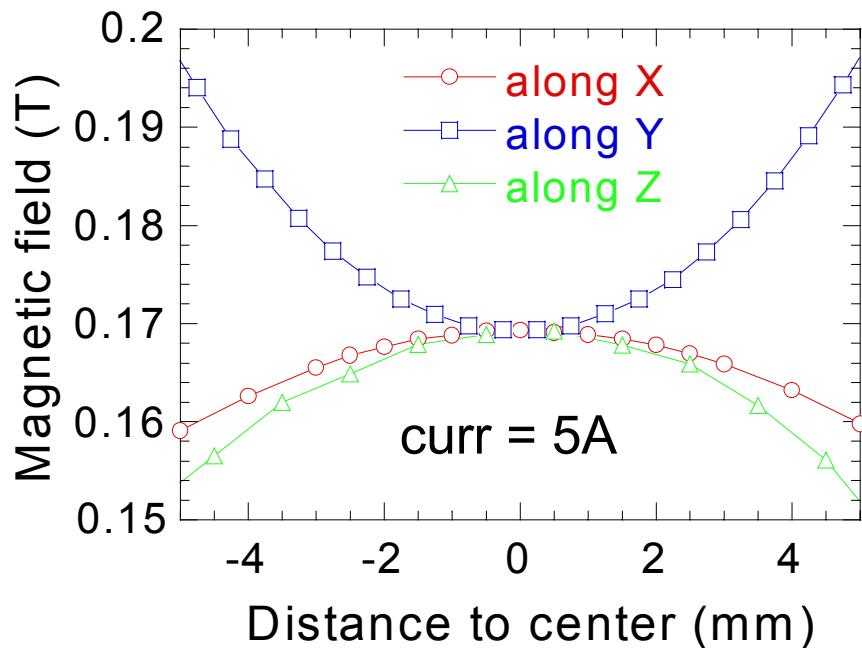
- Polarisation analysis on  $2\theta$  arm
- 2D detector on  $2\theta$  arm

# The magnetic device

---



$H$  vs current  
2 configurations

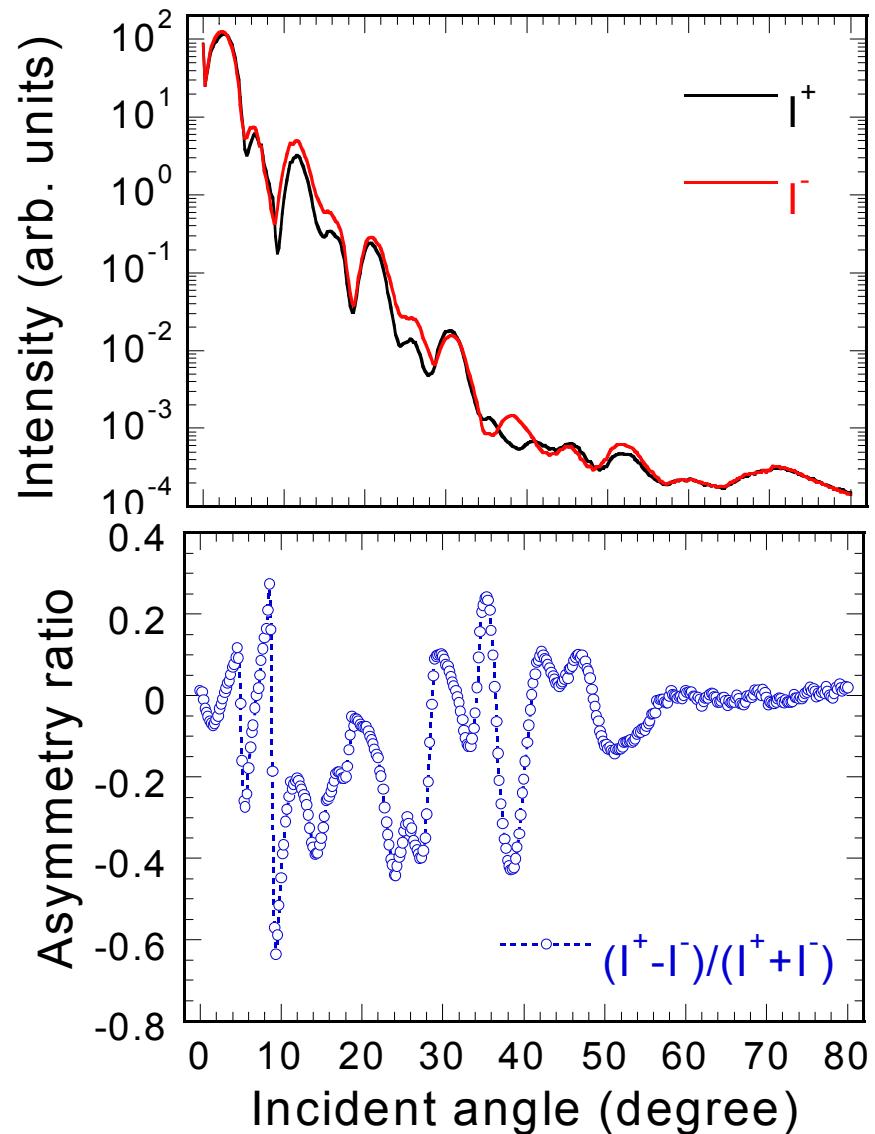
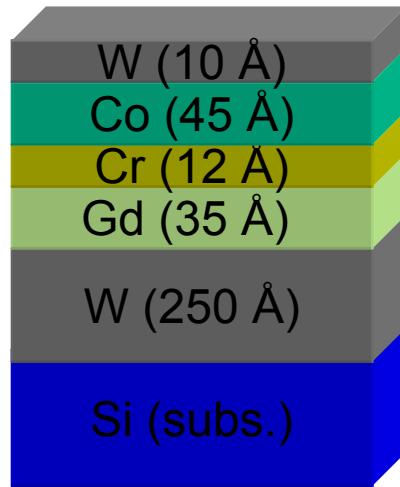


$H_{\text{Trans}}$  vs distance to center  
along 3 directions

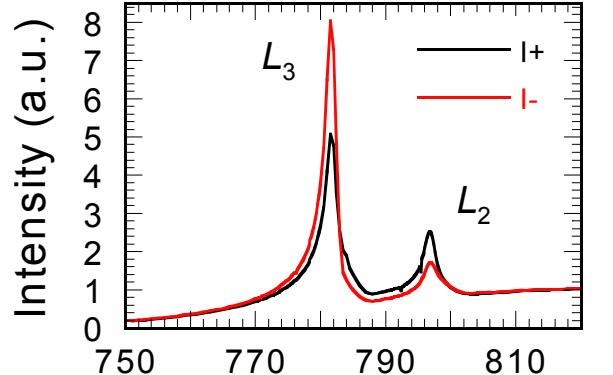
# Interlayer exchange coupled Co/Cr/Gd trilayers

- coupling between Co and Gd through a metallic spacer (Cr, Pt)
- possible change of the sign of the coupling as a function of the nature and the thickness of the spacer layer
- study of magnetic profile throughout the spacer

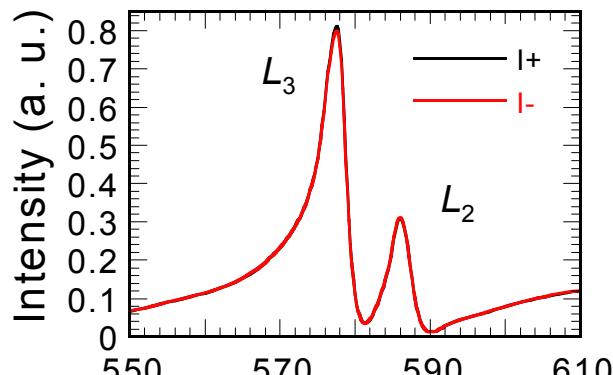
Trilayers studied  
→ illustrate  
RESOXS  
capabilities



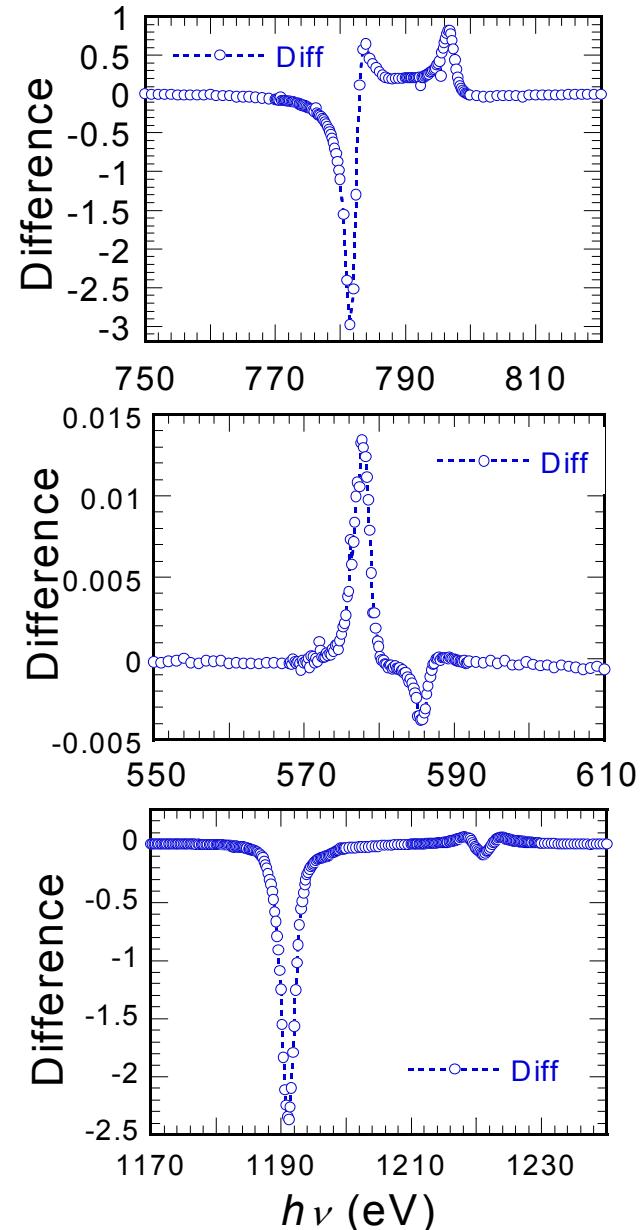
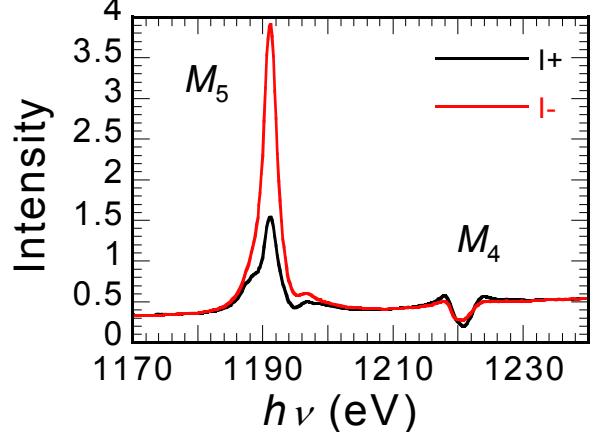
Co edge  
 $\theta = 11$  deg  
 $T = 300$  K



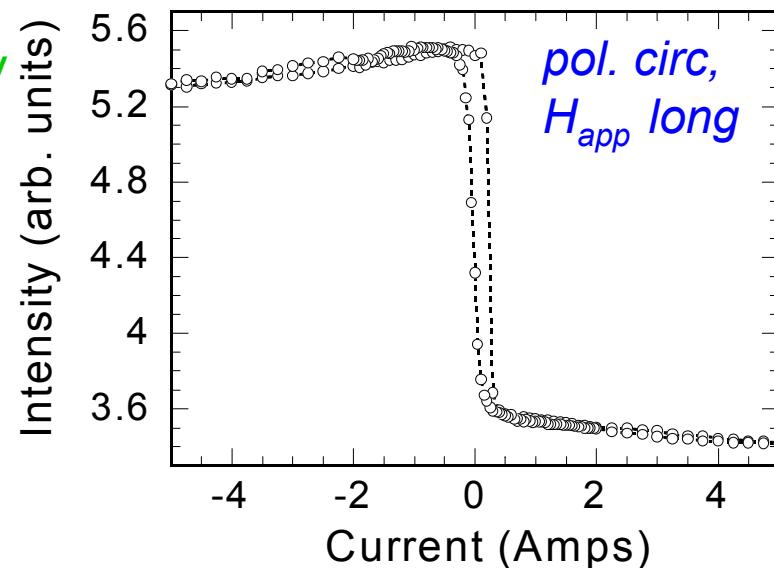
Cr edge  
 $\theta = 15$  deg  
 $T = 50$  K



Gd edge  
 $\theta = 7.2$  deg  
 $T = 50$  K

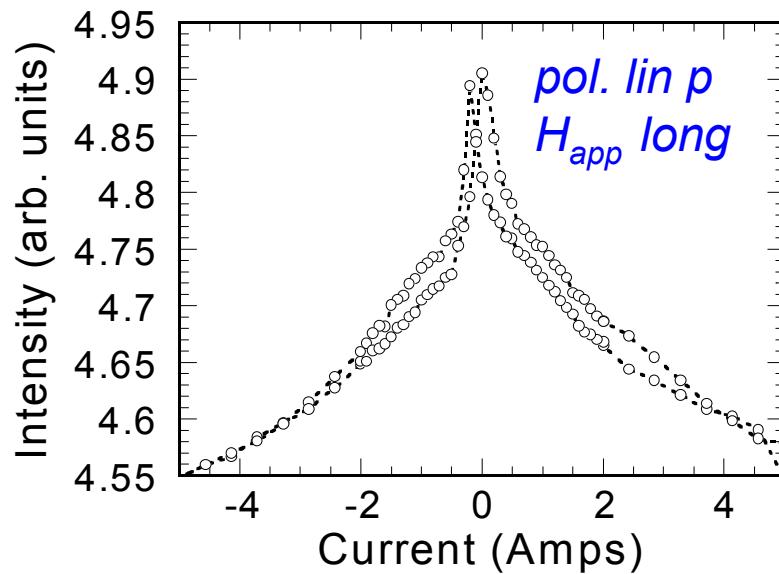


$h\nu = 778.1$  eV  
 $\theta = 11$  deg  
 $q = 0.15 \text{ \AA}^{-1}$   
 $T = 300\text{K}$



Co magnetic moment along the applied magnetic field

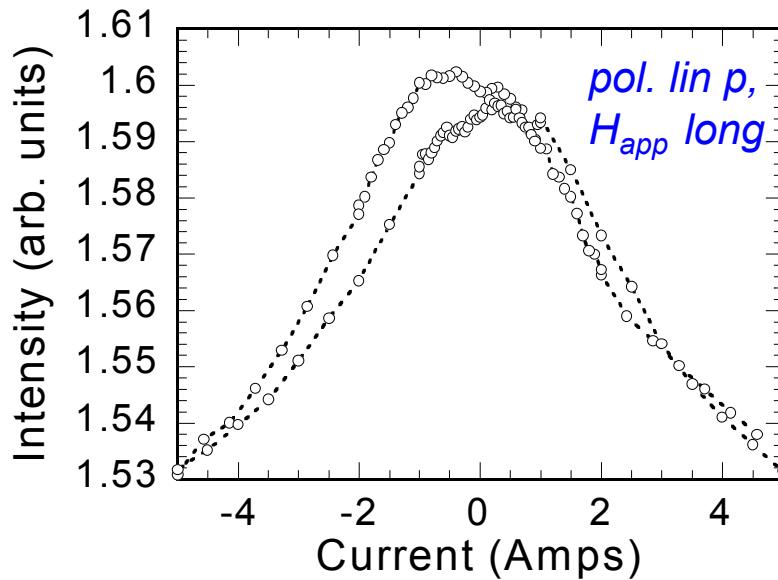
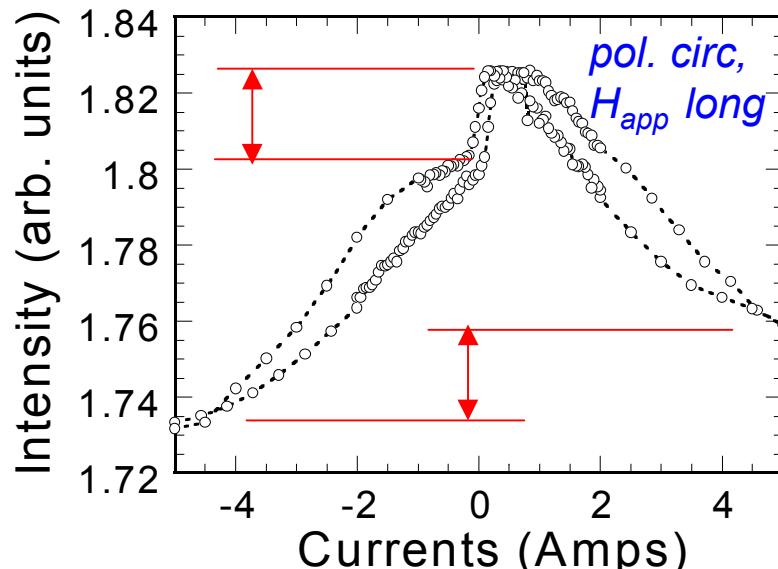
Mostly the longitudinal component



Observation of a transverse component at  $H=0$

In plane rotation of the Co magnetic moment

$h\nu = 574.1$  eV  
 $\theta = 15$  deg  
 $q = 0.15 \text{ \AA}^{-1}$   
 $T = 300\text{K}$



Induced magnetic moments

2 components:

- longitudinal likely pinned to Co at interfaces

- transverse

extension ?

# CoCrGd

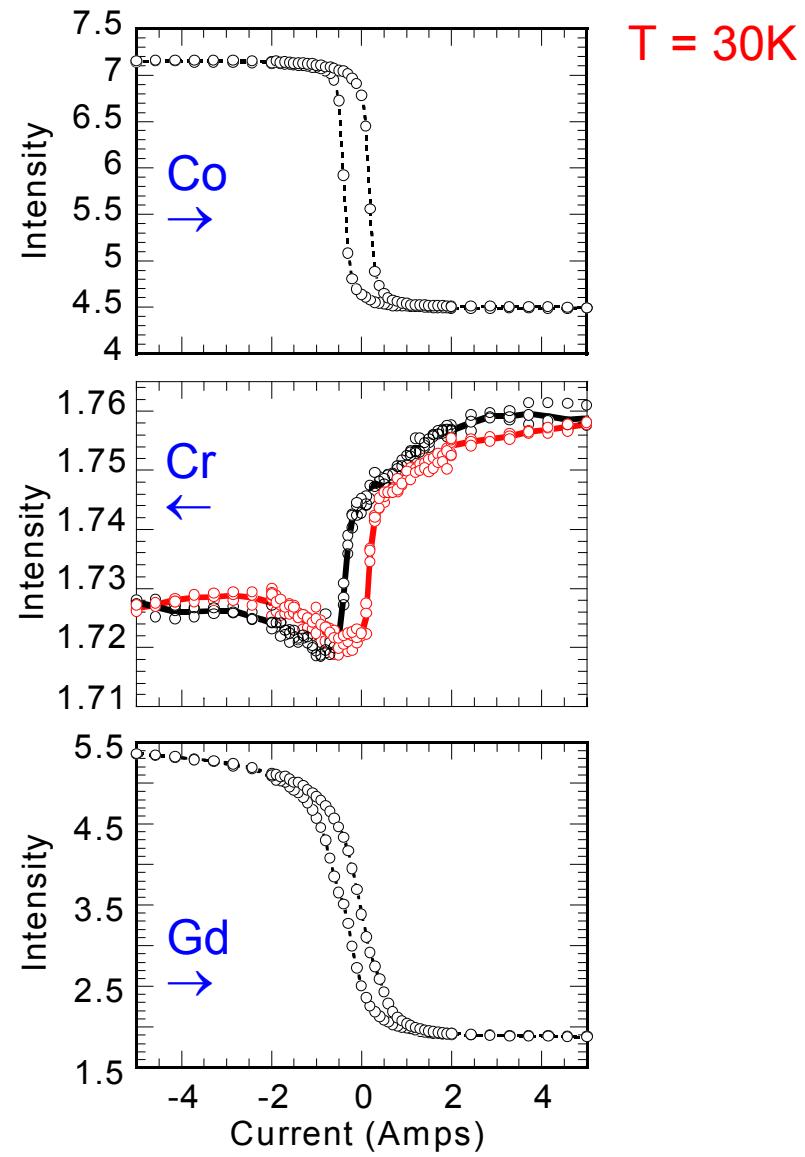
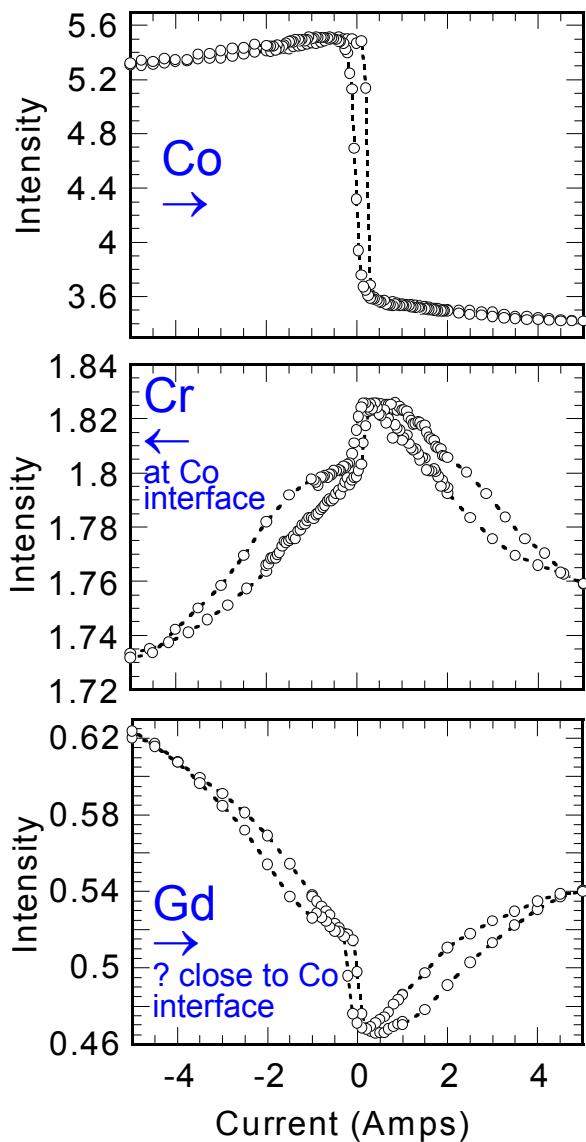
## Hysteresis loops at room and low T

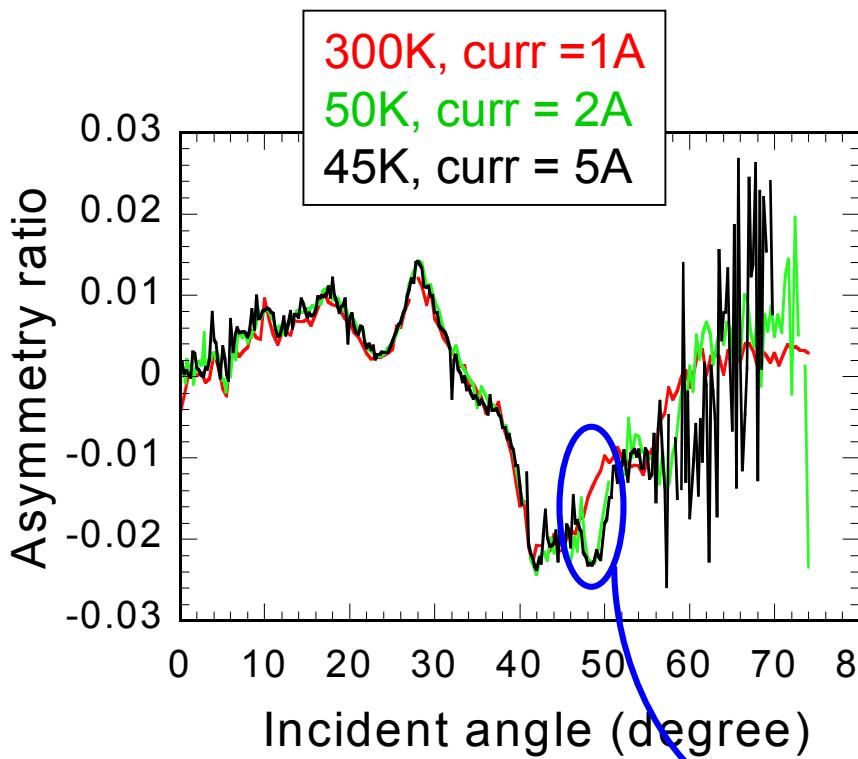
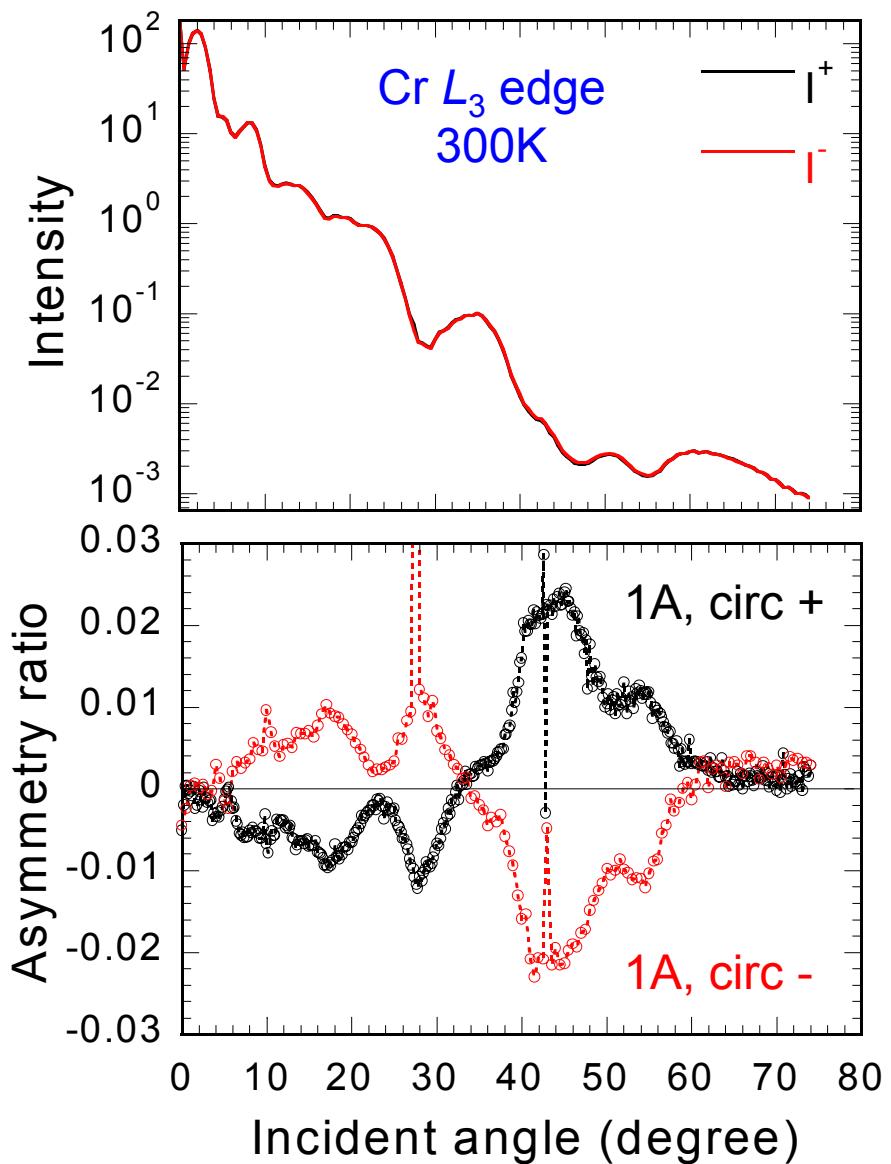
T = 300K

$h\nu = 778.1 \text{ eV}$   
 $\theta = 11 \text{ deg}$   
 $q \approx 0.15 \text{ \AA}^{-1}$

$h\nu = 574.1 \text{ eV}$   
 $\theta = 15 \text{ deg}$   
 $q \approx 0.15 \text{ \AA}^{-1}$

$h\nu = 1189.6 \text{ eV}$   
 $\theta = 7.2 \text{ deg}$   
 $q \approx 0.15 \text{ \AA}^{-1}$



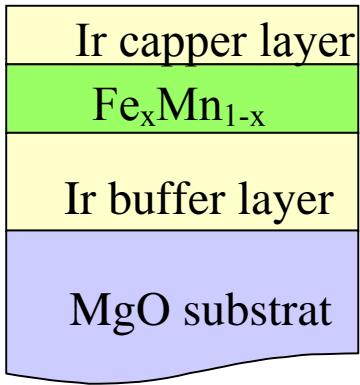


**Effect of temperature?**

- no increase of mag. moment amplitude
- no change in the depth profile ?

# Quantitative analysis

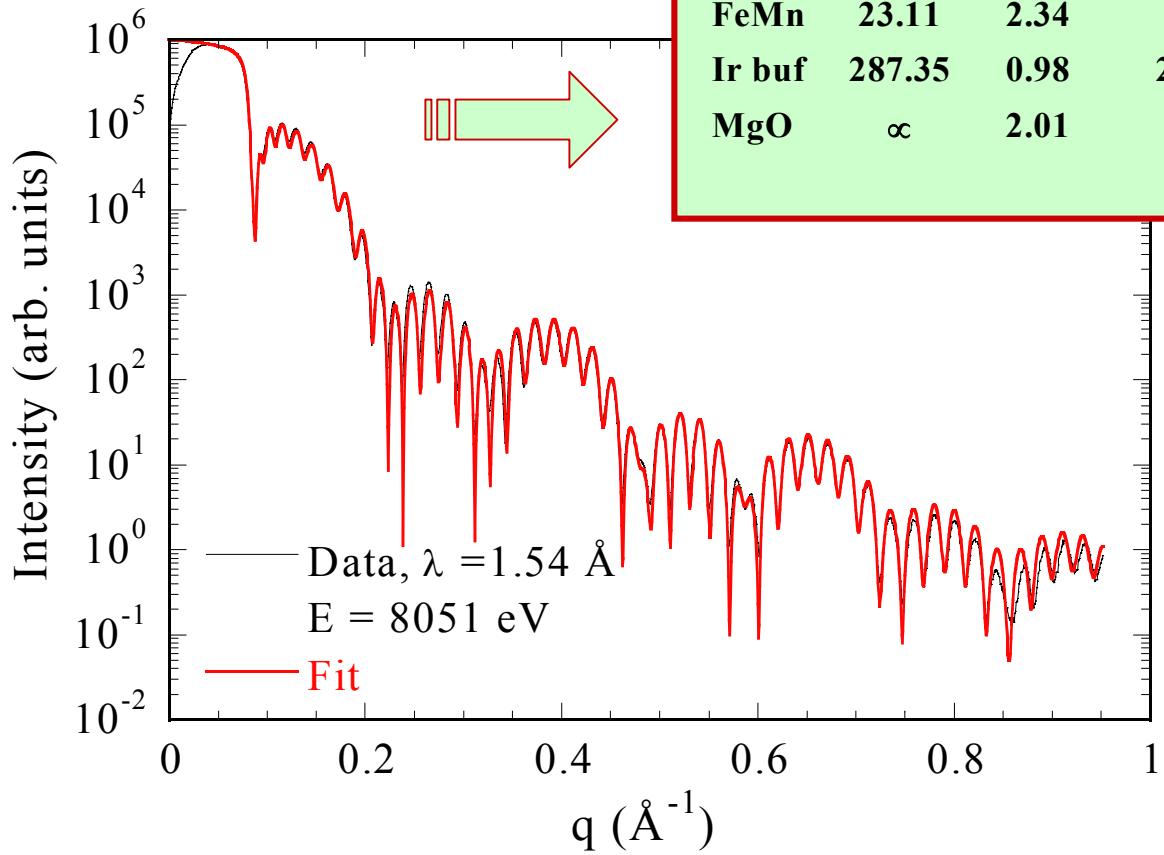
# Structural parameters



## Nominal Parameters:

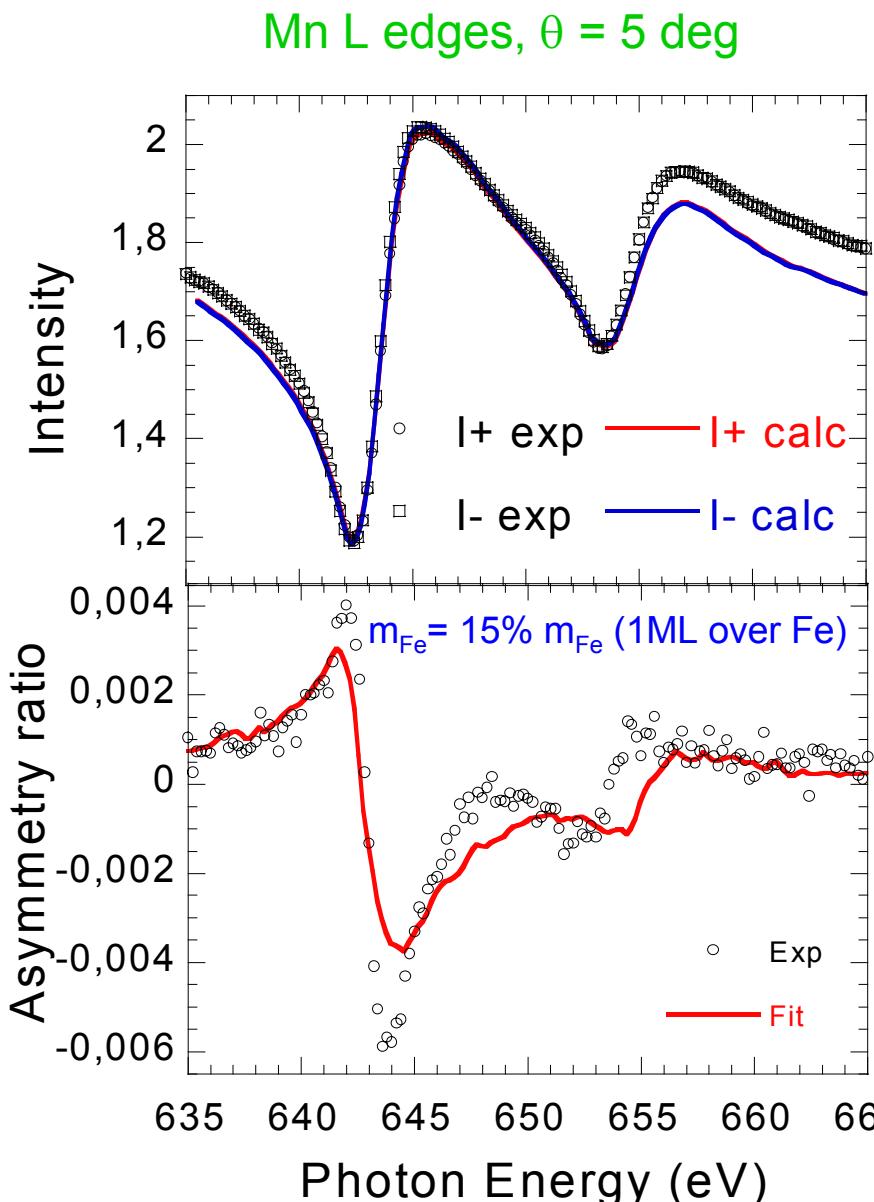
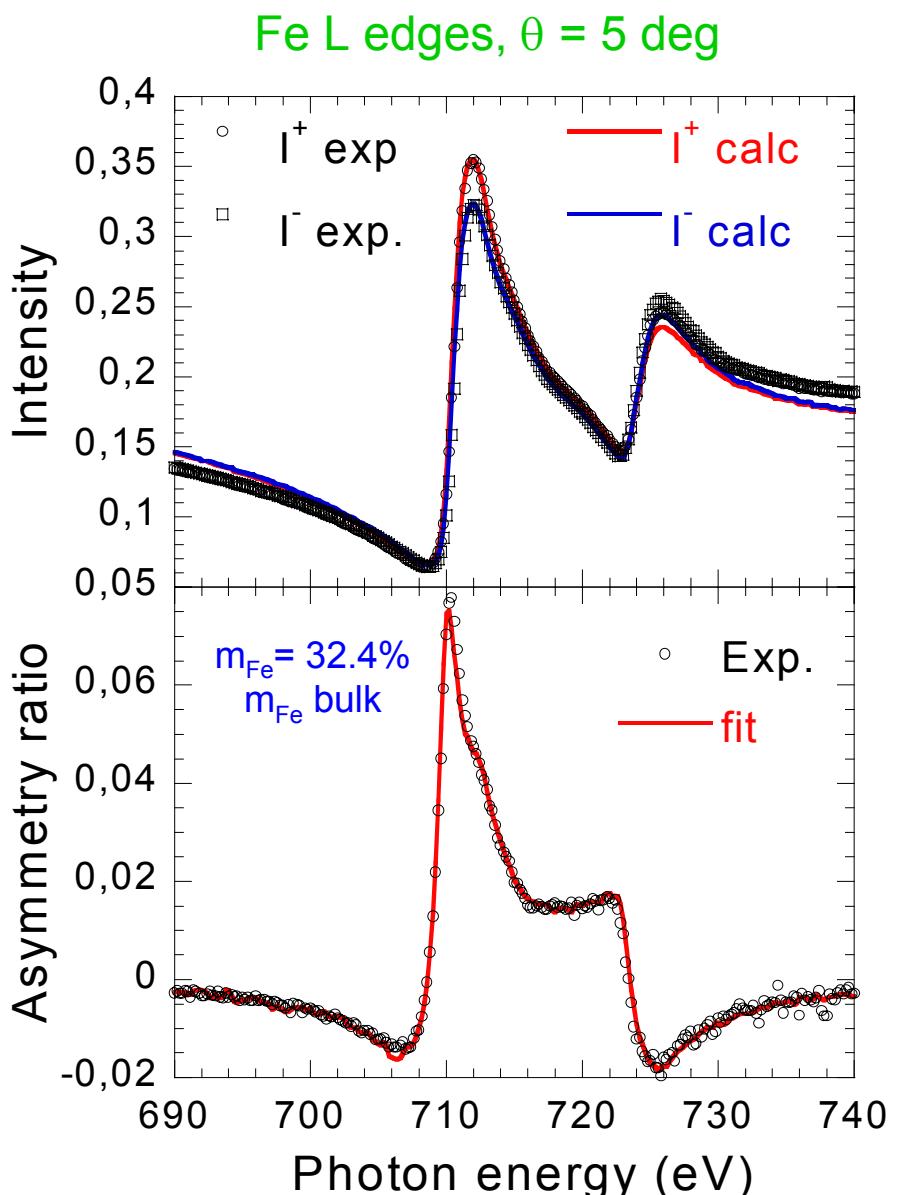
Ir(001)  
 $d_{//} = 2.715 \text{ \AA}$   
 $d_{\perp} = ? \text{ \AA}$   
density ? > bulk  
 $t_{\text{buffer}} = 300 \text{ \AA}$   
 $t_{\text{FeMn}} = 30 \text{ \AA}$   
 $t_{\text{capper}} = 30 \text{ \AA}$   
roughness ?

## Magnetic properties of Fe<sub>70</sub>Mn<sub>30</sub> alloy thin film E. Bontempi, PhD Thesis

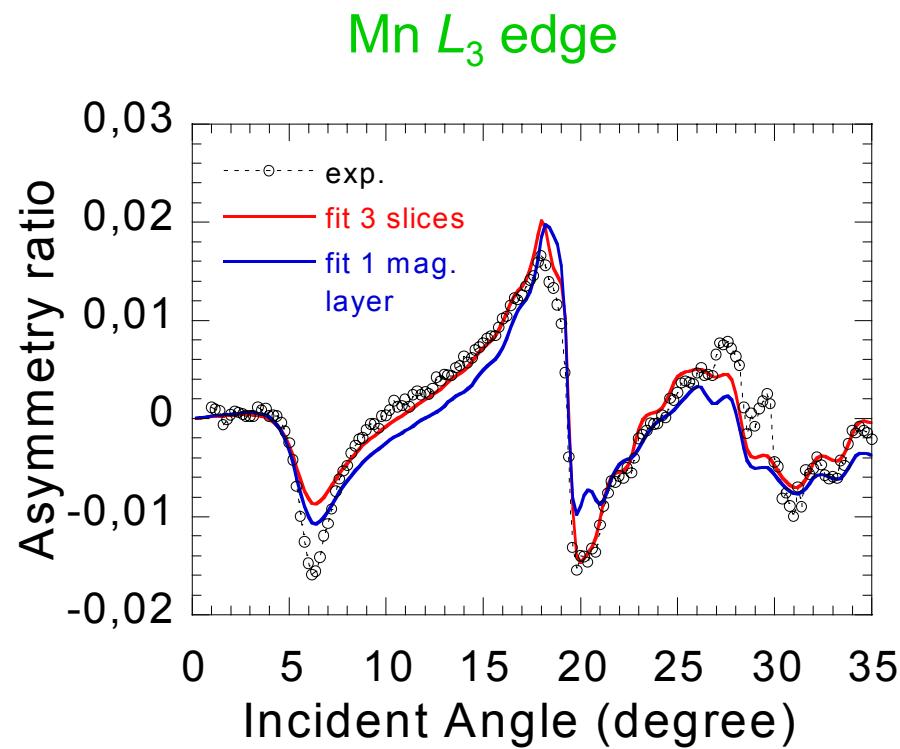
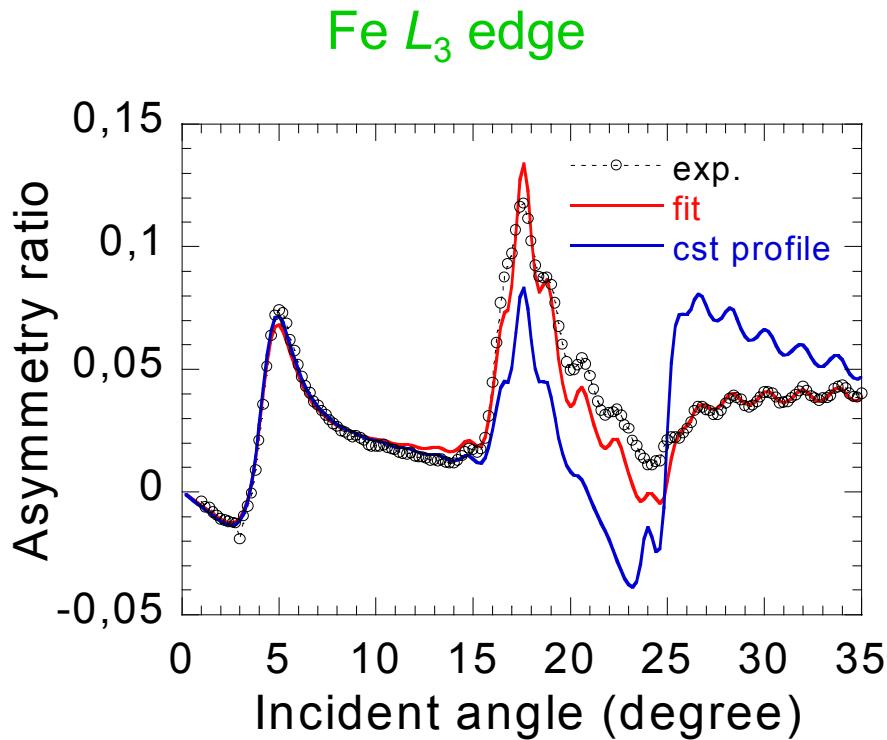


# Quantitative analysis

*knowledge of MO constants*



# Quantitative analysis



2.5 Å, 0.2 m<sub>Fe</sub>  
17 Å, 0.35 m<sub>Fe</sub>  
2.5 Å, 0.2 m<sub>Fe</sub>

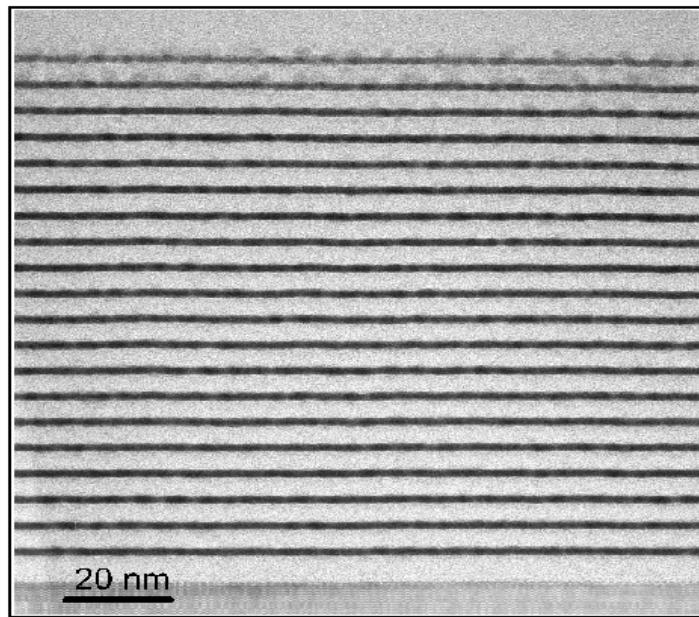
3.9 Å, -0.06 m<sub>Mn</sub>  
15.5 Å, -0.15 m<sub>Mn</sub>  
3.3 Å, -0.25 m<sub>Mn</sub>

more a magnetisation gradient?  
Mn distribution?

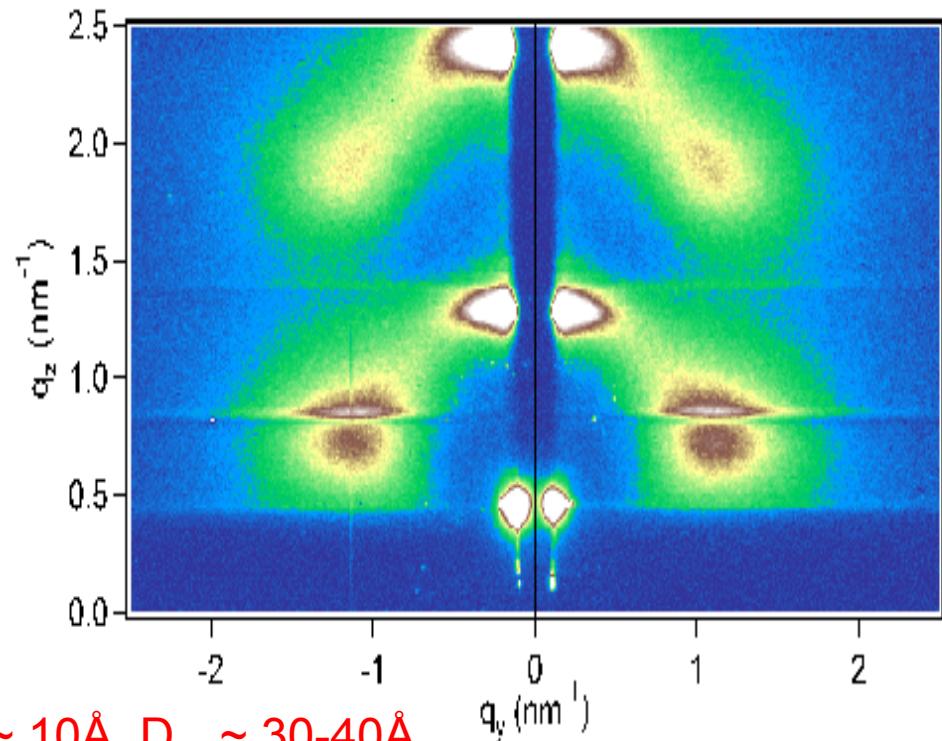
# FePt/C a granular multilayer

Annealing and ordering (phase  $L_{10}$ ) → high density recording media  
Large Magnetocrystalline anisotropy properties  
Role of the matrice on the magnetic properties  
Interface, core-shell structure?

TEM as-prepared sample

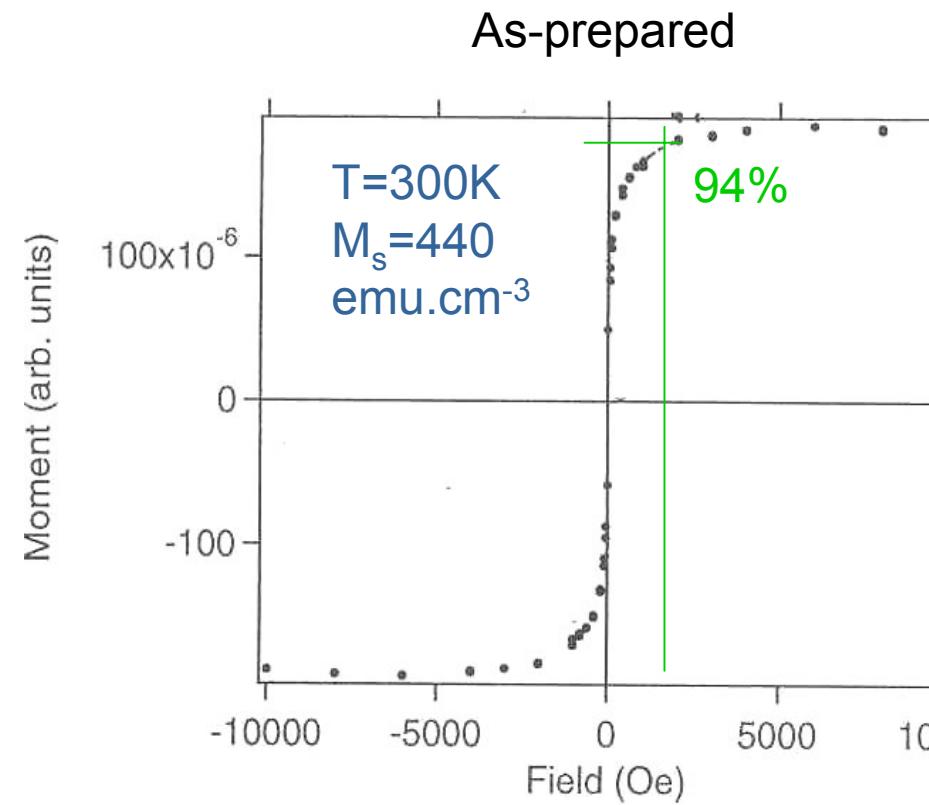
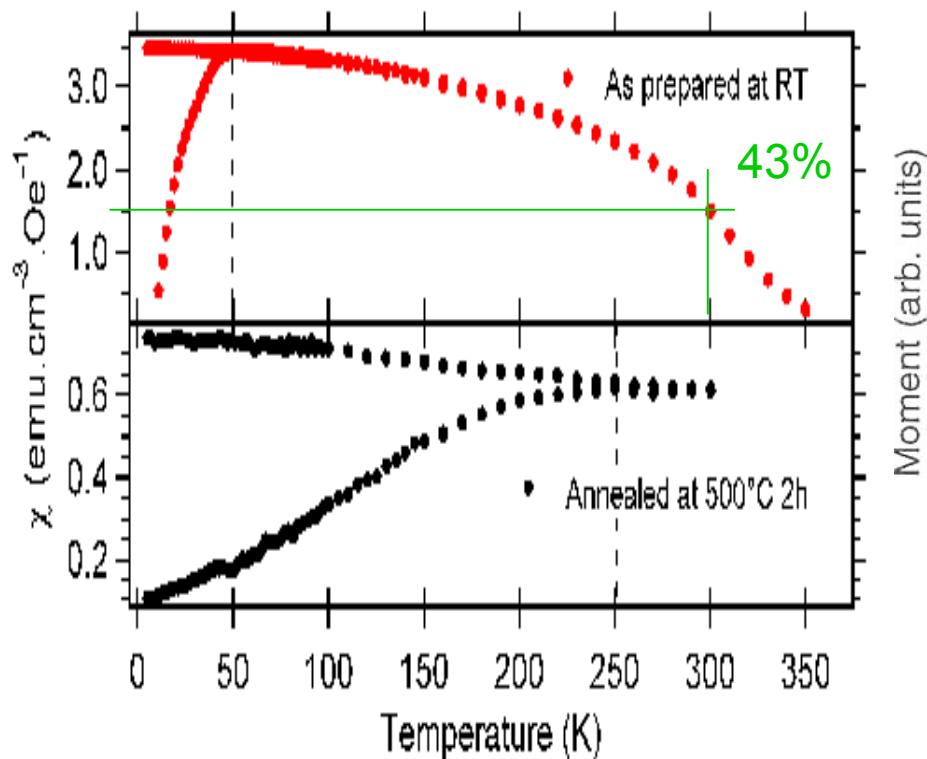


GISAXS as-prepared sample

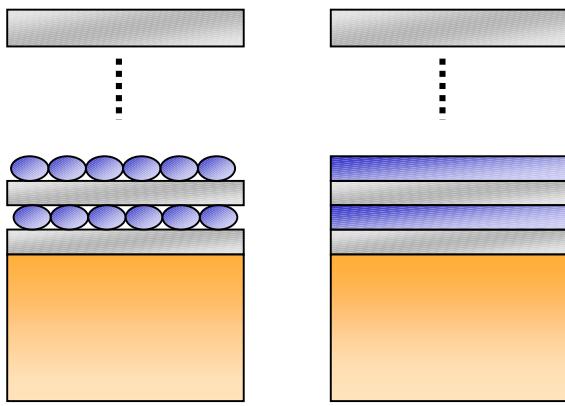


Particle size  $D_z \sim 10\text{\AA}$ ,  $D_{xy} \sim 30-40\text{\AA}$

# FePt/C a granular multilayer



# FePt/C a granular multilayer



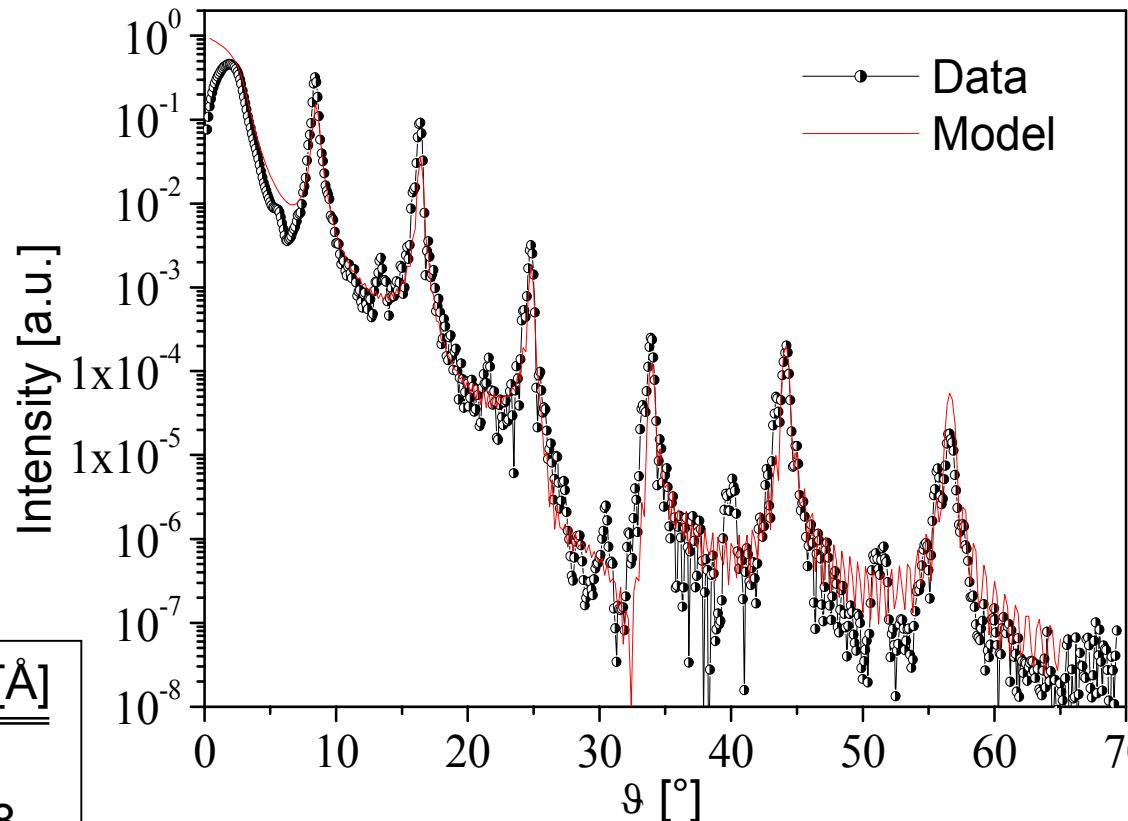
Sample:  
granular  
film

Model:  
continuous  
film

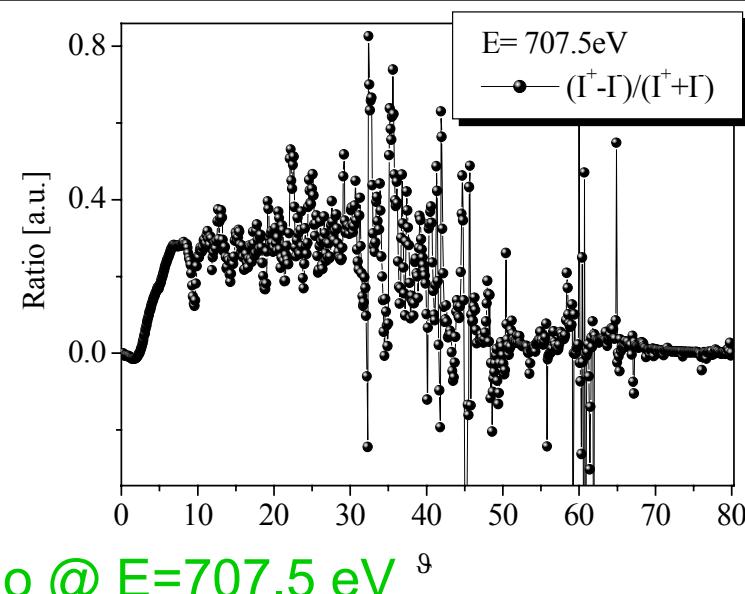
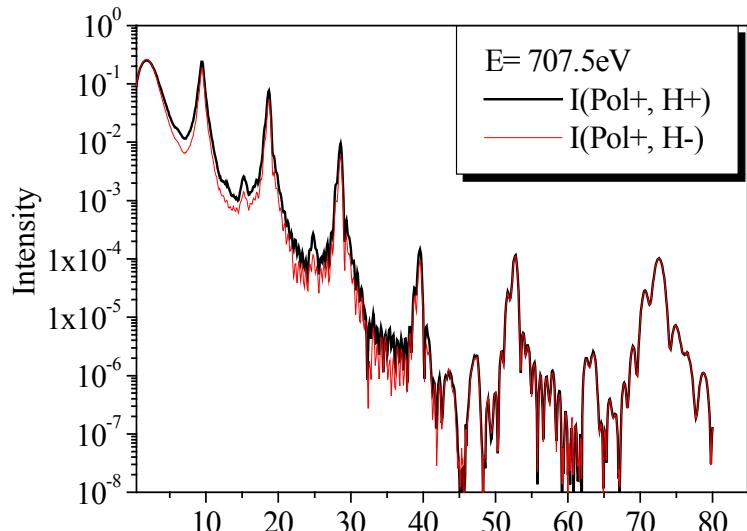
model → *alloy*  
13%C in FePt layers  
(granular nature of the layer)

Layer	$t (\pm 0.5) [\text{\AA}]$	$\sigma [\text{\AA}]$
Cap C layer	44	5
FePt layer	11.5	3.8
C layer	43.8	2.5
$\text{SiO}_2$ layer	20	2.5

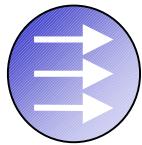
Multilayer simulation through the optical formalism



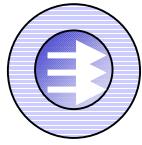
# FePt/C a granular multilayer



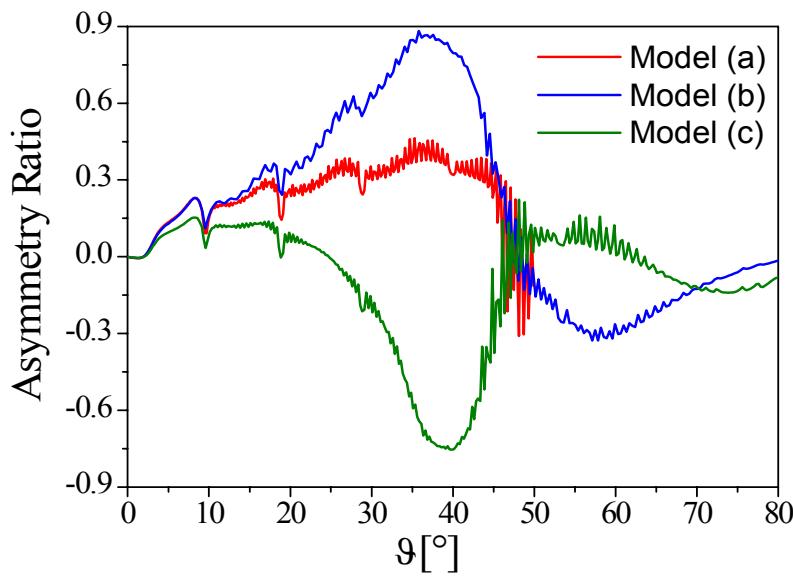
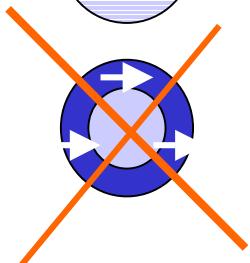
(a) uniform magnetisation



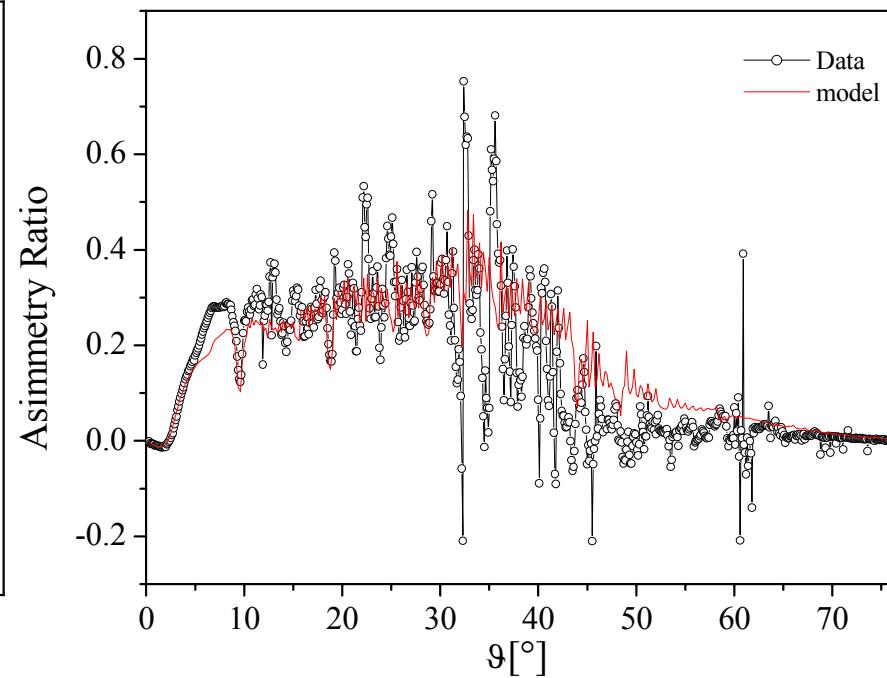
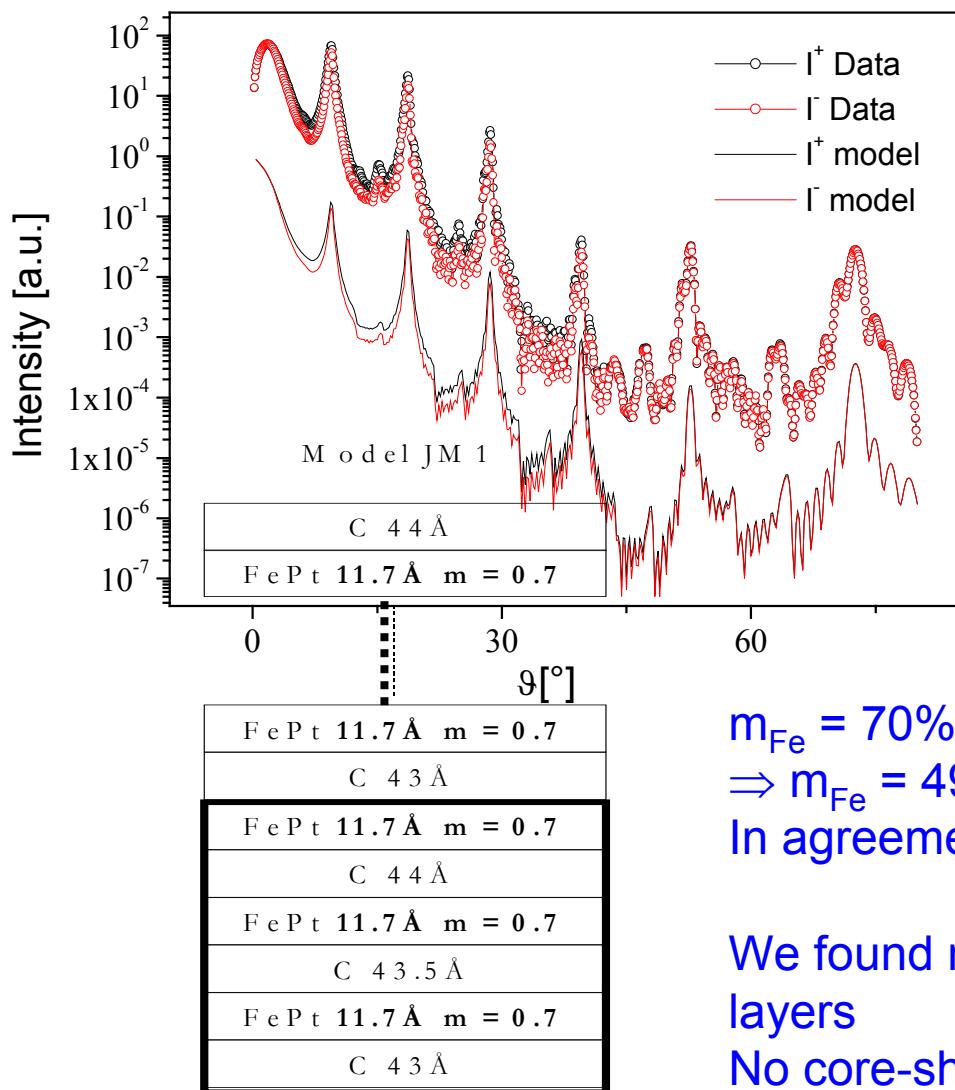
(b) magnetic core  
(non-magnetic shell)



(c) magnetic shell  
(non-magnetic core)



# FePt/C a granular multilayer



$m_{\text{Fe}} = 70\% m_{\text{Fe}}^{3d} (\text{bulk } \sim 2.1 \mu\text{B}, \text{ MO constants})$   
 $\Rightarrow m_{\text{Fe}} = 49\% m_{\text{Fe}}^{3d} (\text{FePt } \sim 3 \mu\text{B})$   
 In agreement with SQUID

We found magnetic moment constant all over the layers  
 No core-shell or a small reduction at interfaces from E-scans at high angles

# SUMMARY

---

---

- Species selective  $q$ , energy, field scans provide useful information on magnetic properties
- Depth resolved magnetism
- Knowledge of energy dependence of MO constants necessary to fully exploit these techniques
- Different scattering configuration probe different magnetic components

# About new beamline and endstation

---

---

- need of well defined polarisation states (linear s, linear p, circular)
- scan over a large angular range
- amplitude of magnetic field large enough → 1T?
- different orientations for H (avoid UHV chamber opening and sample misalignment)
- avoid layer contamination at low T
  - UHV ( $10^{-9}$ ,  $10^{-10}$ )
  - another cooled point ?
- XMCD/XMLD in the same chamber at the same time
- polarisation analysis on detector arm

# Thank you

---

G. Carbone

→ LCG

N. Jaouen

→ LCG , ESRF ID12

E. Bontempi

→ LCG, Brescia

Urs Saub, V. Scagnoli

→ SLS

C. Quitmann

→ SLS (SIM )

J. Voiron, C. Meyer

→ Louis Néel Lab

D. Babonneau

→ Poitiers

W. Felsch group

→ Göttingen

S. Andrieu, H. Fischer

→ LPM Nancy